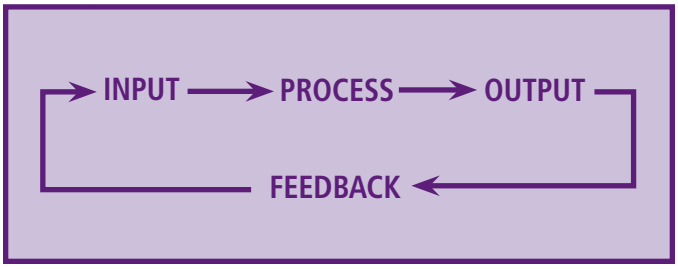
# SYSTEMS AND OPTIMIZATION

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A System is a means of achieving a desired result. It has input, process, output, and feedback loops. The system approach can also be considered a way of thinking. Whenever you are posed with a problem or a case study, simply break it down into smaller sub-systems to simplify the approach.

For example, an automobile has systems and sub-systems: mechanical systems (gears and pulleys); electrical systems (battery, wiring and computers in newer cars); and fluid systems. As the driver, you become the input part of the system when you feed the car information in the form of pressure on gas and brake pedals. You manipulate a wheel mounted to a column that controls direction of the vehicle. The automobile converts the input to process, obeying the driver's signals and converting it into output. Does the vehicle "want" to engage its four-wheel drive? Will the brakes "choose" to function correctly when the driver "miscalculates" and has to slam on them only ten feet from a tree or another vehicle? If one of these systems fails, the driver certainly wants to have feedback. In a vehicle, the gauges and displays give one form of feedback— from the fuel gauge to the large warning lights that tell you simply that something is wrong with your engine. We do not think of these "feedbacks" consciously until a crisis arises, like looking down at your speedometer after passing a police vehicle.






## VOCABULARY

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|---|---|
| Feedback loop (n): the path by which some of the output of a circuit, system, or device is returned to the input. | Gauge (n): any device or instrument for measuring, registering measurements, or testing something, especially for measuring a dimension, quantity, or mechanical accuracy. |

# INPUT



*Input: The instructions or data used by a system to carry out a task.*

Inputs can vary but fall into several categories. They can be in many forms; however, we will discuss the top three. These are people, data, and time.

People have the ability to control their own environments and do so through input. They can design products and systems in order to safeguard a want or need of a single person or millions of people. People can make decisions without having data or information, data. These decisions are not always the best for the desired goal. Through ethical practices and sound decision making, people are always important in the systems process.

Data are everywhere in our lives, from the statement that customers receive about their bank account to the box scores in the Sunday paper, data are all around us. Data are the most critical inputs that an engineer or designer can have to attack a problem. For example, if you were to predict how many cars traveled on a road in a week's time, you would need to collect data. Civil engineers place counter boxes that have hoses attached to them that count the number of times vehicles passing over them every day. These boxes, placed in strategic places along travel routes, get the data that the engineers needs. These data can then be transferred and organized to tell a story. The story might allude to facts that might otherwise not be known. For instance, there may be a heightened period of travel during the middle of the day that could account for the increased number of accidents that otherwise could not be explained. The engineers may have to do some deeper investigation to find out why; however, with the data they at least know they have to look further. Was a major business convention in town that week? Did the local school only have half days? These are all questions that can be asked based on the data in order to obtain additional information needed to solve the problem.



Time could be a characteristic that fits well within information; however it is significant enough to be put into its own category. Time is always a factor in the process. If an engineers know that time is limited, they may make decisions that limits what can and cannot be done. Time can be an enemy or a friend. For example, if engineers knew they had three months in the summer to build a new road- way they could plan out what needed to be done each day and each hour. Because of weather, scheduling, and unforeseen setbacks, time becomes a major factor in what gets done on that project. Conversely, if the weather cooperated all summer, all the materials and machinery was available, and no major setbacks occurred, the engineer could actually finish the project early. In some contracts, bonuses are available for finishing a project early. These usually are a defined sum per day, week. or month ahead of a scheduled finish date. There is a precaution though. If safety, materials, and procedures are sacrificed in order to save time or finish early, the engineer and his or her team may create a final design that is flawed or wrong with immediate, future, or unforeseen problems.



# PROCESSES



All systems have actions associated with them. These steps can be completed in different ways and make up the processes in the systems loop. Many different processes can take place in this block of the loop, including problem solving, and production.

The philosophy associated with producing the world's goods and services has changed dramatically in recent years. As multinational corporations struggle to minimize costs while maximizing efficiency, the location of manufacturing facilities in foreign lands has increased significantly. Many firms have found distributing products from a facility close to their customer base more efficient and less costly. Others have found it more cost-effective to produce their products in places with cheaper labor, higher quality, and more favorable government policies. Therefore, in the realm of global production, firms can commonly have dozens of production facilities in different countries.

Typically, much of today's research, design, and development is done in central locations though actual production may occur in different parts of the world. Engineers may find that their work involves communication and input from colleagues around the globe. In addition to international telephone and e-mail communication, production problems, quality control issues, and meaningful design changes may necessitate frequent international travel.




The typical foreign-based manufacturing facility is usually staffed by foreign national employees. Almost all of the production staff and skilled and unskilled labor are hired from the particular region. The corporate staff is usually involved in the initial facility start-up, the employee hiring and training, and the monitoring of the manufacturing process. Often, corporations use local engineering talent for maximum efficiency, so many firms recruit international students attending U.S. colleges and universities to fill these roles. The overall objective is to provide the technical expertise to the local

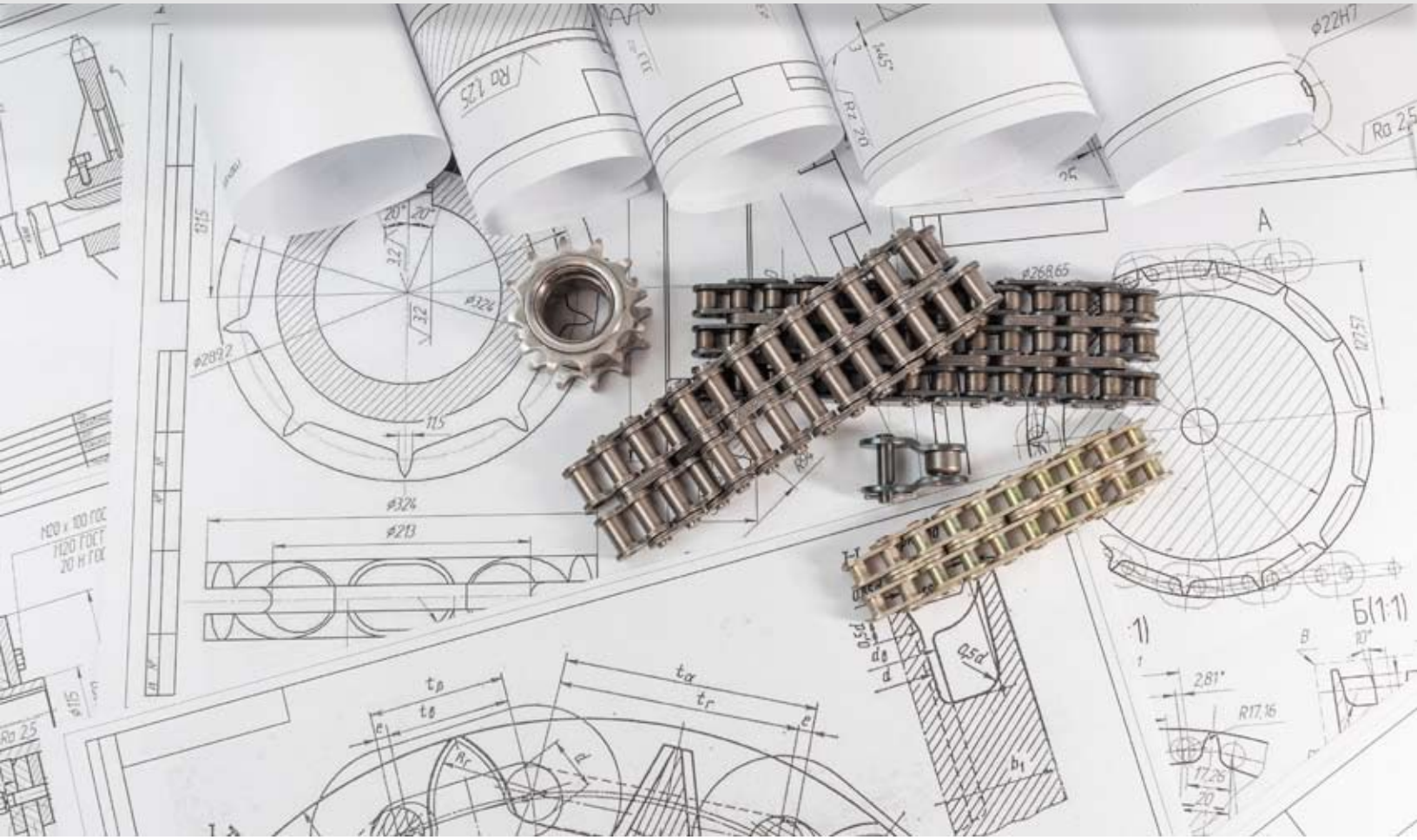
| VOCABULARY | |
|---|---|
| Firm (n): a partnership or association for carrying on a business. | Customer base (n): the group of customers who repeatedly purchase the goods or services of a business. These customers are a main source of revenue for a company. |

labor force so it will be able to run the operation. The number of actual U.S. employees permanently assigned to a particular facility will probably be small. Their role will be to manage the operation, deal with immediate issues, and serve as the liaison between the home office and the production facility.

A similar situation exists for foreign firms that have established manufacturing facilities in the United States. Most of the on-site corporate staff will be from the home country, but the objective is to hire and train as many U.S. employees as possible. Foreign firms will invest time and money to train these individuals to adapt to their particular business style. For many employees at these facilities, gaining a technical knowledge of the engineering process and a proper cultural perspective can be critical. Certain methods or procedures may actually arise from a particular cultural background, belief system, or age-old methodology. This can be quite an adjustment for U.S. workers hired by these firms. Often, newly trained technical employees may be recruited from American colleges and universities to take advantage of their solid technical education and a broader understanding of cultural issues.

Many of the ideas and concepts which have revolutionized the manufacturing industry have been a result of the globalization of world production processes. Engineers and managers are adopting some of the best manufacturing technologies developed in different countries. Today's world of manufacturing is often a blend of the best practices and procedures gained from the integration of systems and concepts from engineers around the world. Manufacturing is truly a global enterprise in the life of today's engineer.

There are three major parts of production. They are routing, scheduling, and controlling.

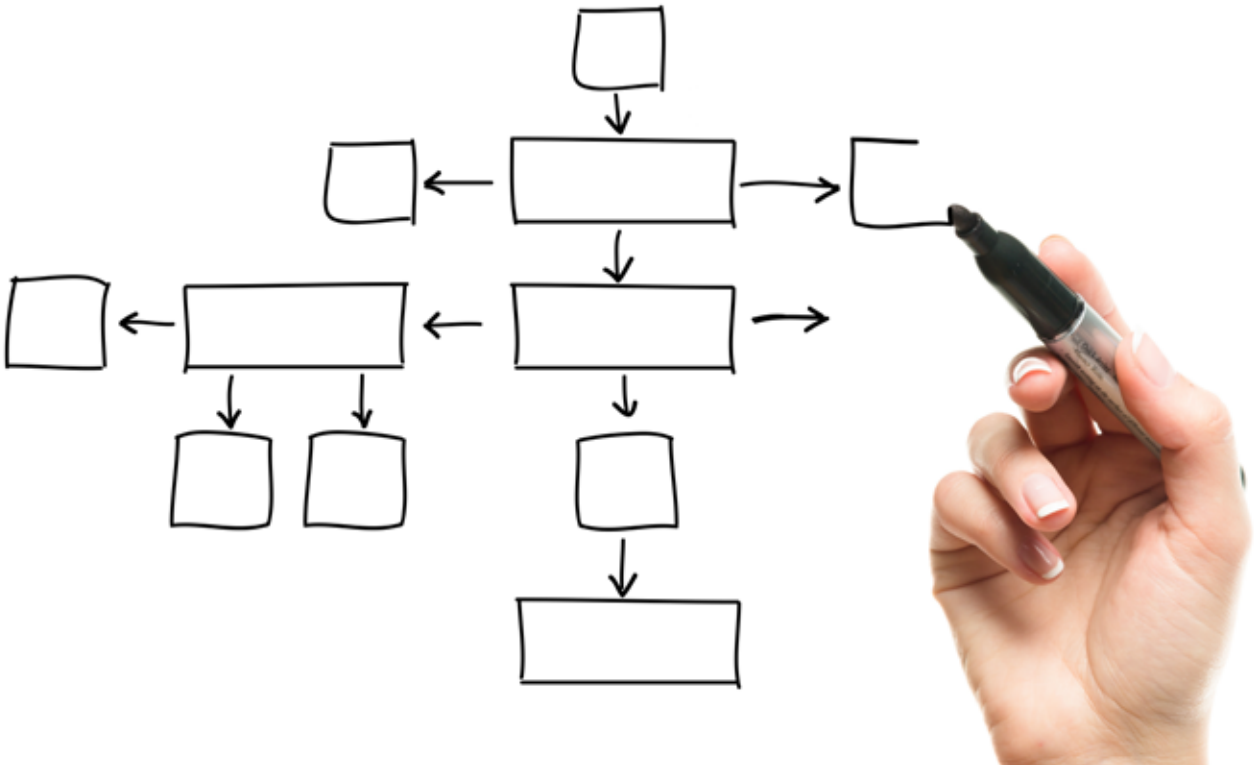


## ROUTING

Routing—Production planners or industrial engineers have to determine the number of parts to be built and when those parts or products will be ready for consumers. These planners are responsible for routing the product through the facility. They determine the exact route that an item will travel though a plant when in production. This layout is done in advance of any parts being made and can resemble a maze of lines in a diagram that explains this in detail. For example, if you were to make a pizza in your kitchen this is the process that would take place:

This is every step usually taken when making a frozen pizza. It is explained as if it were a procedure in a manufacturing or production plant, but it is an effective way to describe how complicated a simple process can be if done on a large scale.

| | |
|---|---|
| | *1. Locate resources for the pizza, usually from the grocery store.* |
| | *2. Arrange financing for the product.* |
| | *3. Arrange for the transportation of the product to storage on site.* |
| | *This would involve driving to and from the grocery store.* |
| | *4. Store the product until ready for use (usually in freezer).* |
| | *5. Prepare machine for heating. (Turn on the stove.)* |
| | *6. Remove product from storage.* |
| | *7. Remove packaging from product.* |
| | *8. Wait for machine to heat to temperature.* |
| | *9. Place product in machine to be heated.* |
| | *10. Wait 15 minutes.* |
| | *11. Locate tools to remove product from machine heating it (usually hot pads).* |
| | *12. Remove product from machine.* |
| | *13. Stage product in a safe and sanitary place for cooling.* |
| | *14. Locate tools to cut product into pieces.* |
| | *15. Locate sanitary items needed to serve product.* |
| | *16. Bring serving items and staged cut product to same area.* |
| | *17. Separate product onto serving items.* |
| | *18. Distribute product.* |



## SCHEDULING

Materials, workers facilities, and machinery are items that require planning in the scheduling process. In order to determine how many of a product will be made, production planners do several things. They forecast an estimated demand for the product; this may come in the form of a detailed market analysis or an evaluation of a competitive product. Customer orders also determine the minimum number of products to be made. Production planners might also have to allocate parts or products to be used by the business itself. For instance, if a company manufactured trash bags, it would obviously also need trash bags in the everyday course of its business. It would have to determine how many bags to add to manufacturing to supply its business with the bags. Lead time is another thing that a production planner has to consider in scheduling. Lead time is the amount of time needed to get a particular part made, deliver a new machine to the plant, or have materials shipped to the production facility. In some startup businesses, lead time may also be an issue with personnel hiring.

Just in time (JIT) manufacturing is a system that reduces the inventory of raw materials, parts, or product components to the minimum. These materials are scheduled to arrive at the production facility as they are needed for use.




| VOCABULARY | |
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| Forecast (v): to predict (a future condition or occurrence); calculate in advance. | Allocate (v): to set apart for a particular purpose; assign or allot. |
| Lead-time (n): the period of time between the initial phase of a process and the emergence of results, as between the planning and completed manufacture of a product. | Startup (adj): of or relating to the beginning of such a venture or project, especially to an investment made to initiate it. |

## CONTROLLING

Product level data reports are needed during production to assure a company that schedules from the plant are on time and that departments and workers are completing tasks on time. Changes in the way products are made usually come in small forms from an evaluation of the product level data. These reports not only catalog vital information for the current product, but are useful in the future development of other products.

Quality control is vital in the production of any consumer goods. Quality control involves inspecting materials, work products, and labor before and during production.

Materials have to be inspected when they arrive at the production facility. A quality product starts with quality materials. This doesn't necessarily mean high price. Quality materials can be defined as materials that meet the specification of a company for use in production. These materials may have to be tested for certain characteristics needed for the product. If the testing shows that the materials are not what are specified, the shipment of materials may be rejected. This may be as simple as a Rockwell C hardness test, or as complicated as a scanning electron microscope (SEM) test or a tensile test.




Work in progress checks are made frequently during production. When a material is processed, it has to be checked as it goes through the production process. For example, when first stamping the hoods for the Mini-Cooper vehicle, plant personnel realized that the formed sheet metal was tearing where the hood was contoured. Engineers' initial discussion suggested the counters had to be removed so the tears could be eliminated. The designers of the vehicle and the contours in its hood felt this was unacceptable and that an alternative solution maintaining the hoods contours had to be found. After careful planning, the engineers provided specifications

| VOCABULARY | |
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| Quality control (n): a system for verifying and maintaining a desired level of quality in an existing product or service by careful planning, use of proper equipment, continued inspection, and corrective action as required. | Electron microscope (n): a microscope of extremely high power that uses beams of electrons focused by magnetic lenses instead of rays of light, the magnified image being formed on a fluorescent screen or recorded on a photographic plate: its magnification is substantially greater than that of any optical microscope. |
| Tensile (adj): of or relating to tension. | |

for the sheet metal to be thicker where the contours were being stamped to insure that the hoods would not tear. In the end, the solution worked and satisfied not only the engineers but the designers as well. Quality control was an important part of this process. If the tears had not been realized before the cars left the plants, it could have required an extensive, expensive recall of the vehicles to replace the hoods.

Work in progress checks produce three ratings on the product status. Rejects are parts that do not meet standards or cannot be repaired. Reworks are items that fail to meet standards but can be repaired. Accepted parts meet company standards for that point in the process. Final products have to meet these three company standards initially set forth in the design process. If these standards have certain minimums (e.g., must support at least 10 pounds), then the final products will have to meet the minimum standards to be allowed to go to the consumer. These minimum standards may be checked using machines, jigs, and fixtures, or even the human eye for visual checks. If a product has to meet a minimum standard and is to be tested for that standard in its final form, it has to be destroyed. This process is called destructive testing. It may be that the part is put though multiple uses or split in half to check its internal features for flaws. These destructively tested parts are not sent to the customer but are discarded or documented as a part of a group of parts that have passed a test. Many times inspectors will label a part "inspected by" with a stamp or a sticker to assure the customer that it has been through the process.



## VOCABULARY

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| Standard (n): a rule or principle that is used as a basis for judgment. | Jig (n): a plate, box, or open frame for holding work and for guiding a machine tool to the work, used especially for locating and spacing drilled holes; fixture. |

# OUTPUT



*Output: The final product of a system or device*

An output can be a myriad of things. It might be goods or services, products, structures, messages, or even people moved from one place to another. These outputs are direct results of or anticipated outcomes from the design. If a company wanted to provide homes for families in an undeveloped area of a state, it would go through many different processes in order to complete that goal. In doing so, it would produce a final product and unwanted outputs such as scrap wood, metal, and other wastes associated with its product. Pollution is another large unwanted output. Pollution can come in many forms. Chemical by products are a large problem for companies that make film for cameras. They have to spend millions of dollars each year to dispose of these chemicals properly. Noise pollution is generated by construction companies building new homes for people. While they may not have to pay because they pollute neighborhoods with noise, they must follow city rules in regard to the hours they may operate their equipment and work on a site. Air and water pollution are significant problems for our country. Many companies that produce unwanted outputs must also spend money on systems to clean the air and the water they will put back into the environment. (For more information refer to Chapter 13, Technology/Society Interaction and Ethics.)




**VOCABULARY**

Noise pollution (n): harmful or annoying levels of noise, as from airplanes, industry, etc.

# FEEDBACK

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Feedback generates data that allow the user, consumer product, system, or company to make informed decisions about what comes next. This could be used by a system to regulate itself at some set time interval. For example, if the temperature within the cooling system of a passenger vehicle reaches a certain temperature, a mechanical part (thermostat) is opened in order to allow fluid to flow to other parts of the engine. If this feedback information is ignored, or the mechanical part does not respond to the feedback, the entire system may be jeopardized and could fail catastrophically. Similarly, in that same vehicle, feedback gauges allow the operator to monitor the vehicles characteristics. These same monitoring actions can be done automatically by complex designs that can adjust levels based on feedback from a system. Nuclear power plants, space agency vehicles, monitoring systems, and interactive homes are examples of essential feedback.




## VOCABULARY

Feedback (n): the furnishing of data concerning the operation or output of a machine to an automatic control device or to the machine itself, so that subsequent or ongoing operations of the machine can be altered or corrected.

# OPTIMIZATION

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Optimization is doing the most with the least. A crude but distinct example would be cutting a 2" by 2" square out of as piece of paper. Would cutting it out of the center be the best solution? Or might a better solution be to use the edges of the paper in a corner to eliminate two unnecessary cuts and have a large portion of the paper uninterrupted for future use?

Optimization can save companies millions of dollars if done correctly. For example, an engineer took a position with a respected company that built landfill tractors. These tractors and their parts were cut out of one-inch thick steel by a computer numerically controlled plasma cutter. The company had laid out the parts on large sheets of steel with no apparent order. This engineer's first assignment on the job was to cut waste in the production. The first place he looked to optimize was in the layout of the cuts from the one-inch thick steel. By going through and organizing how the parts were laid out and cut, he learned that he could save over 25 percent of the steel that would otherwise be wasted. This 25 percent that went to recycling was now being used to make additional parts for the tractor and, therefore, saved money. Think of it this way. If that 25 percent savings represented a monetary savings of $1,000 and the engineer's labor was $500 for the work, the company would have saved five hundred dollars. However, if the company made on an average 50,000 tractors annually, the savings would total 25 million dollars that year alone. Most design problems we face have no definitive answer.

Most solutions are a series of compromises, which in turn allow the product to function well. An engineer or technician must assess all the parts of a problem and optimize each before the job is resolved. Webster's defines optimization as "The procedure or procedures used to make a system or design as effective or functional as possible, especially the mathematical techniques involved."

Optimization moves the innovation process further. It favors gaining understanding by abstract thinking. But rather than diverge, an individual with this thinking style prefers to converge. This results in converting abstract ideas and alternatives into practical solutions and plans. Individuals rely on mentally testing ideas rather than on testing things. People who favor the optimization style prefer to create optimal solutions to a few well-defined problems or issues. They prefer to focus on specific problems and sort through large amounts of information to pinpoint what's wrong in a given situation. They are usually confident in their ability to make a sound logical evaluation and to select the best option or solution to a problem. They often lack patience with ambiguity and dislike dreaming about additional ideas, points of view, or relations among problems. They believe they know the problem.

| VOCABULARY | |
|---|---|
| Optimization (n): the fact of optimizing; making the best of anything. | Definitive (adj): having its fixed and final form; providing a solution or final answer; satisfying all criteria. |

# LEARNING ACTIVITIES

ACTIVITY 10.1 | *System loops* | **TIME:** 1–2 class periods, 4 days at home collecting data.

In this case study, student teams of three will examine bicycles to determine what systems they have. The teams will also create input, process, output, and feedback loops for each system in order to explain it to the class. A presentation will be required of at least one of the systems of a bicycle. Teams will present detailed information to the class though electronic presentations, physical and graphical models of the specific system, and written text of the system. The instructor of the class will assign the team a specific system and the following are the minimum requirements of the presentation:

1. Define the input, process, output, and Gauge s specifically.
2. Replicate the system to scale (determined by the team) with the use of mechanical design software or through orthographic hand drawings.
3. Replicate the teams' recommended modifications to the system to scale (determined by the team) with the use of mechanical design software or through orthographic hand drawings. This can be an overlay for a hand drawing, a layer in a CAD drawing, or a pop on part for a scale model.
4. Build a scale model of the system assigned to your team.
5. Write a report on the system and describe the specific uses, advantages and disadvantages of the loops, and what your team would design to improve the system.

## REFERENCES

- http://www.trekbikes.com Trek is a privately held corporation that still resides in Waterloo, the small town in Southeastern Wisconsin where, in 1976, five employees started making handbuilt bicycle frames in an old wooden barn. Nearly a quarter of a century later, Trek is the world leader in bicycle products and accessories, with 1,500 employees worldwide.

## CASE STUDY

The philosophy of a bicycle has been around since 1817 when Baron Karl Drais von Sauerbronn invented a walking machine (the Laufmaschine) that helped him get around better. This was not pedal powered; he simply walked along side of it and pushed it for power. In 1865, the first bicycle known as the Velocipede or Boneshaker used pedals to power it.

In the 21st century, you can now build your own bike online through websites like the one that TREK offers. Composite materials, special frames, and complicated aerodynamics are a few of the systems involved in bicycles today. The future of this industry holds many advancements and innovations designed into prototype bicycles every day. Many of these developments may become part of the bicycles sold in stores in the coming years.

## VOCABULARY

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|---|---|
| Orthographic (adj): of or relating to the art of writing words with the proper letters, according to accepted usage; correct spelling. | Aerodynamics (n): the branch of mechanics that deals with the motion of air and other gases and with the effects of such motion on bodies in the medium. |

# LEARNING ACTIVITIES

ACTIVITY 10.2 | *Material Systems Dissection* | TIME: 3–4 class periods

## CASE STUDY

Materials are usually things that society tends to pick off the shelf or purchase based on a known supply. Kevlar was not a viable solution to many manufacturers in the past because it did not exist. Scientist's and engineers created it based on a need. Materials can be created based on parameters defined for a project. In our culture, a many small appliances are found around the home. These appliances are part of what technology has done to improve our lives. The materials used in these appliances are usually selected based upon availability, ability to serve the purpose, and economics. As you carefully dismantle the appliance, attempt to determine the purpose of each part and why the material that was used to make it was chosen.

## REFERENCES


- ENERGY CONCEPTS, INC. (1999) Materials Science Technology: Solids. Pg. 2.23–2.25
- http://www.science-ed.pnl.gov/mst.stm This is the Department of Energy's Materials Science Curriculum website. The site gives a glimpse into the full document with information and selected activities in PDF format.


*Part A*

1. Carefully dismantle the appliance using the tools needed to remove the appliance's casing and inner parts. In this process, attempt to keep each of the parts intact. In your journal, note the type of appliance dismantled, your observations, and your impressions when dismantling it.

2. Categorize the disassembled parts, and place them into containers or bags labeled metals, ceramics, polymers, and composites, such as in Figure 15. Do this to the best of your ability.

*Part B*

1. Obtain a piece of poster board. Use the parts from your appliance to make a poster about your appliance. Use your creativity. The poster could include parts, historical developments, the appliance as you envision it in the future, an alternative to this appliance, etc.

## VOCABULARY

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|---|---|
| Kevlar (n): a brand of aramid fiber. | Ceramics (n): the art or technology of making objects of clay and similar materials treated by firing. |
| Economics (n): the science that deals with the production, distribution, and consumption of goods and services, or the material welfare of humankind. | Polymer (n): a compound of high molecular weight derived either by the addition of many smaller molecules, as polyethylene, or by the condensation of many smaller molecules with the elimination of water, alcohol, or the like, as nylon. |
| Composite (n): made up of disparate or separate parts or elements; compound. | |

# LEARNING ACTIVITIES

ACTIVITY 10.3 *Texas Traffic* **TIME:** 5–10 class periods

## CASE STUDY

The Houston TranStar Automatic Vehicle Identification (AVI) traffic monitoring system collects real-time information showing current travel conditions on Houston area freeways and high occupancy vehicle (HOV) lanes. This information is provided to personnel within the Houston TranStar Center for detecting freeway congestion. This travel information is provided to the public through media reports and is displayed on selected roadside electronic message signs and the Houston TranStar website (http://traffic.tamu.edu/).

The system uses Automatic Vehicle Identification (AVI) technology developed by the Amtech Systems Division of TransCore to collect the real-time traffic information. Houston was the first city to apply AVI technology for monitoring traffic conditions.

The AVI system operates through the use of AVI antennas and readers, which are installed on structures along Houston freeways. The AVI antennas and readers monitor the passage of vehicles equipped with transponder tags. The transponder tags are powered by a small battery, which enables them to reflect signals transmitted from the antennas/readers.

The system uses vehicles equipped with transponder tags as vehicle probes. The main source of vehicle probes is commuters using the EZ-Tag automatic toll collection system installed by the Harris County Toll Road Authority (HCTRA). Transponder tag readers are placed at 1- to 5-mile intervals along freeways and HOV lanes. Each reader senses probe vehicles as they pass a reader station and transmits the time and location of the probes to a central computer over a telephone line. As the probe vehicles pass through successive AVI readers, software calculates average travel times and speeds for a roadway segment. The averages are made available to software, which provides the data for the Houston TranStar website.

In this case study, students will access the TransStar website (or your local website that has proper information) to study information and habits of drivers as well as trouble spots within a system. Breaking into groups of three, students should study the habits and mistakes of drivers over a five-day period. The student team is required to collect and log major accident areas, major delay areas and areas that it determines may be a future area of concern. Eleven major arteries flow into and out of the Houston area. Each team will be assigned a specific road for data research.

## VOCABULARY

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|---|---|
| Probe (n): something that probes, examines, or tests. | Artery (n): a main channel or highway, especially of a connected system with many branches. |

## ASSESSMENT

Students will be required to present their spreadsheets and the charts derived from the sheets to the entire class. They may choose to create large posters or PowerPoint presentations, or they may draw the chart on a chalkboard or whiteboard for the class. The presentation should include maps, charts, and pictures that explain their specific researched road as well as the main accident spots, slowdowns, and predicted future problem spots. The following questions should also be answered in written format by each member of the group:

Identify the input, process, output, and feedback parts of this system.

What are the pros and cons of this technology?

How would you use it if it were available in your hometown?

Could this technology provide a positive impact on your community? Why?

## REFERENCES


- http://traffic.tamu.edu/ This is the Houston TranStar website where the data can be downloaded and traffic can be observed. It also has links explaining how the technology works and other topics to make the lesson more comprehensive.
- http://www.dot.gov/about_dot.html This page gives you information about the Department's of Transportation's organization, key officials, mission, and other important information related to managing the department and accomplishing its mission.
- Asphalt Nation: How the Automobile Took Over America, and How We Can Take It Back, Jane Holtz Kay
- ISBN: 0520216202; Publisher: University of California Press (November 1998)
- This book is an excellent reference for alternative transportation methods and a bit of history on the automobile.
- http://www.microsoft.com/office/excel/default.asp This is Microsoft's Excel homepage. It has tips and tricks, usage procedures, and the top ten frequently asked questions. If the site changes, search Microsoft's website, or search your school's software.